Proceedings of John Lee Pratt
International Symposium on the

Role of Magnesium in Animal Nutrition

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1983

see also: Shockey, W.L., and R.L. Reid 1984. Partition of Mg in forage as affected by fertilization, species, growth stage and sample preparation. Agron. J. 76:565.
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Role of Magnesium in Plants

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Magnesium is one of 13 mineral elements required by plants and one of at least 17 required by animals. The element was first isolated in chemically pure state by Sir Humphry Davy during the years 1807 to 1812 and its necessity for plant growth was shown by J. von Sachs and W. Knop in the 1860's. Its presence in the chlorophyll molecule was detected by R. Willstätter in 1913. More details on the history of Mg research appear in earlier reviews (1, 8, 11 and 20).

Photosynthesis

Photosynthesis is the process whereby light energy is converted into chemical energy within green plants. The process depends directly upon the chlorophyll molecules within the chloroplasts of the plant. Chlorophylls are Mg porphyrins with Mg making up about 2.7% of their molecular weight (13). The two major forms of chlorophyll, a and b, occur in higher plants in a ratio of approximately 3:1 (14).

The Mg-containing molecules of chlorophyll a and b are effective in photosynthesis whereas the Mg-free pheophytins are without effect (10). Thus, the Mg atom plays an indispensible role in the process. The Mg atom may endow the chlorophyll molecule with the particular absorption spectrum that is necessary for energy reactions that occur in photosynthesis. Comparison of the visible absorption bands of ether solutions of chlorophyll a and b with the emission lines of Mg° and Mg^{+} indicates almost a line-for-line correspondence of certain absorption and flourescent bands of the chlorophylls with the emission spectra of excited states of the Mg° atom and of the Mg^{+} ion but not with the Mg^{++} ion (10).

Additional evidence that the Mg atom is directly involved in the primary photochemical process is that all Mg-containing porphyrins can be oxidized much more readily than if Mg is absent from the molecule. Even more conclusive is the fact that photochemically oxidized chlorophyll has an absorption spectrum identical with that of pheophytin. This shows that it is the Mg atom alone which is oxidized in the process of the photochemical reaction (10).

Magnesium in chlorophyll represents about 10% of the total Mg in the leaf, but the chloroplasts contain at least half of the leaf Mg (17). Chlorophyll Mg may be as high as 18% (14) of the total leaf Mg in lush growing forage. The proportion of chlorophyll-Mg (acetone soluble) decreases and the water extractable fraction increases (table 1) as herbage matures (19).

TABLE 1. PARTITION OF HERBAGE MAGNESIUM BETWEEN ACETONE AND WATER (ADAPTED FROM TODD, 1962).

	Total Mg DM basis	Mg in fraction as % of total Mg		
		100% Acetone	Water	Residue
	%			
Mixed herbage, young, leafy	.18	11	54	35
Mixed herbage, seeding stage	11	4	75	21

Magnesium ions are actively incorporated into the chlorophylls in expanding leaves (2). However, ^{28}Mg was not incorporated into the chlorophylls of non-expanding leaves implying that there was no turnover or continued synthesis of chlorophyll.

Magnesium, in contrast with other divalent cations, is readily translocated in the phloem of plants (16). After 24 hours 7 and 11% of the absorbed ^{28}Mg was exported from treated bean and barley leaves, respectively. The 7% of the ^{28}Mg exported during the 24-hour period is compared with values of .05% for ^{45}Ca and 25% for the more mobile ^{42}K. A high proportion of the total Mg, often over 70%, is diffusible through the plant in association with inorganic anions or organic anions such as malate or citrate (8).

In Mg deficient plants, symptoms will generally appear first in older leaves as Mg is translocated from old to new leaves (6). Green plants show some type of chlorosis when Mg is deficient, and the loss of chlorophyll is often followed by the appearance of other colored pigments. A decrease in chlorophyll concentration is considered to be the prime cause of the inhibition of photosynthesis in Mg deficient leaves. A close relationship exists between net photosynthesis and Mg concentration in leaves. For example; photosynthesis in corn (15) declined rapidly as the Mg concentration declined from 200 μg/g fresh weight (165 meq Mg/kg dry matter (DM) assuming 10% DM). Photosynthesis and photorespiration in sugar beet blades (figure 1) declined rapidly as tissue Mg levels decreased below 200 meq Mg/kg DM (18). A critical level of 150 meq Mg/kg was calculated for sugar beets by these authors (18).

Magnesium deficiency also results in the accumulation of osmiophillic globules and the progressive disruption of the chloroplast membrane (5). The accumulation of globules was also described for barley leaves grown in N, P or Mg deficient cultures (12). Deficiencies of Mg and/or P and N induced similar structural and functional changes in the membrane system of the chloroplast. The similarity of chloroplast membrane damage and accumulation of globules when N, P and Mg are deficient probably arises because of their involvement in energy transport and protein synthesis.

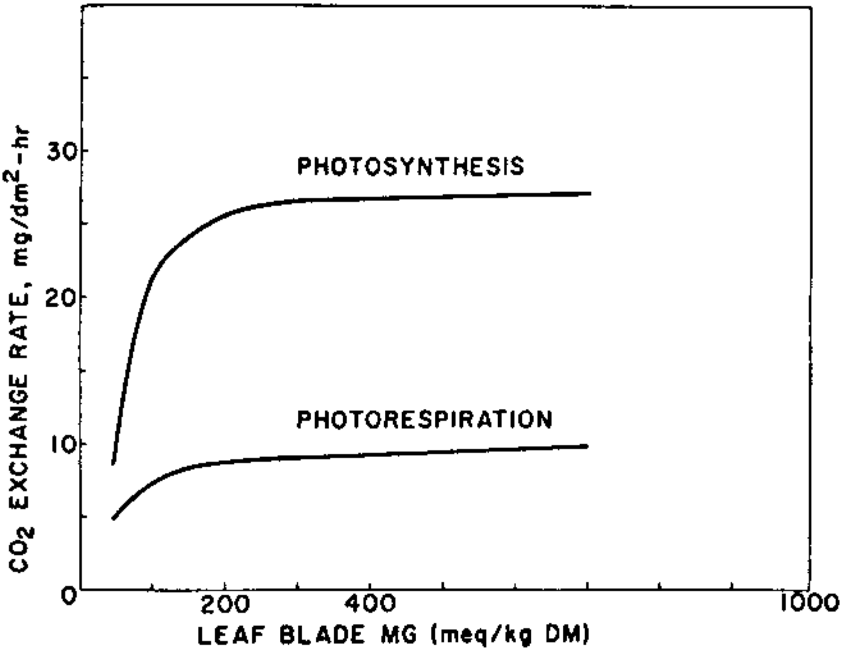

Figure 1. Photosynthesis and photorespiration rates in corn leaf tissue as a function of tissue Mg levels expressed on dry matter (DM) basis, adapted from Terry and Ulrich (18).

Enzyme Activator

In addition to its role in chlorophyll, Mg is the most common activator of enzymes associated with energy metabolism (4) or energy transport, particularly those utilizing adenosine triphosphate (ATP). Magnesium ions chelate rapidly with ATP, polyphosphates, phosphoric esters, inorganic phosphate, hydroxy acids, amines, and amino acids which are components in known ATP-dependent reactions. Magnesium in these reactions lowers the free energy of activation of the rate-determining step (8, 13).

ATP or other high energy phosphate compounds take part in enzymatic reactions. All known ATP-catalyzed reactions show an absolute requirement for Mg ions (7). Other divalent ions such as Mn^{++} or Ca^{++} may replace Mg^{++} in some enzyme reactions, but maximal activity is obtained only in the presence of Mg (8, 13). Magnesium is also a metal activator of enzyme reactions of phosphorylations and some reactions of glycolysis.

Electron transfer in photosynthesis and other enzyme reactions occurs across cell membranes. A schematic of the chloroplast structure is shown in figure 2 amply illustrating the large surface area of membrane material vital to cellular functions. The basic constituent of cell membranes is the phospholipid which controls membrane permeability (3,4,6,9). These phospholipids provide a site on which oxidation and reduction reactions take place. Magnesium deficiency significantly reduces the amount of phosphatidyl glycerol and to a lesser extent, diphosphatidyl glycerol, phosphatidyl choline and phosphatidyl ethanolamine, lipids that are part of the membrane structure (9).

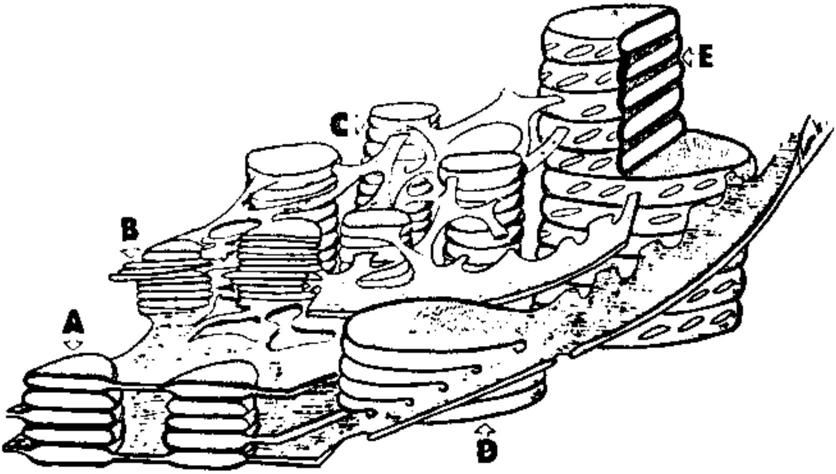

Figure 2. Schematic representation of the membrane stacking in grana (containing chlorophyll) of chloroplasts: A) grana formed of individual discs (small thylakoids) linked by extensive stromal discs; B) perforated stromal lamellae linking grana at several levels; C) frets connecting several thylakoids within the same grana; D) spiral formation of grana membranes; E) spiral fretwork arranged around and interconnecting the individual grana. From Coombs and Greenwood (3). Note the extensive membrane material present in the chloroplast structure.

The formation of phospholipids in mitochondria is restricted when N or P as well as Mg are deficient (9,12). The effects of deficiencies of these minerals come as no surprise since Mg is required for P incorporation into ATP and ATP is the energy source driving many synthetic rections of mitochondria. Additionally, N is a basic component of the protein portion of membranes on which the oxidation and reduction reactions occur.

Magnesium ions are also combined with the phosphate radicals of ribonucleic acid (RNA) and the associated protein. These submicrosomal particles have a critical Mg concentration of 5×10^{-4} *M* (6).

Summary

Magnesium is required as a cofactor in a large number of enzymes involved in energy transport, particularly those utilizing ATP. It is a constituent of the chlorophyll molecule and is required for the normal structural development of the chloroplasts as well as other organelles such as the mitochondrion. Magnesium deficiency would have damaging effects on synthetic as well as metabolic reactions. Magnesium is also important in phospholipid formation and the structuring of cell membranes.

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